

**P4.16 RAIN FALLSPEEDS AND RATES DERIVED FROM AIRBORNE NADIR-POINTING
DOPPLER RADAR MEASUREMENTS**

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1. INTRODUCTION

The use of vertical-incidence Doppler velocity in addition to radar reflectivity may yield information on drop size distribution and therefore result in better rainrate estimates. Doppler velocity can provide useful information on the raindrop size distribution. Doppler velocities from a zenith-pointing radar represent the sum of the mean reflectivity-weighted hydrometeor fallspeed and the vertical air motion. Dual-parameter rain estimation methods using the Doppler velocity, require that the latter can be removed, or is negligible. Atlas et al. (1972) derived relations between Doppler velocity, reflectivity, and rain rate assuming an exponential size distribution for rain. Ulbrich (1994) expanded on this work by deriving the relation between the Doppler velocity and the reflectivity assuming a Gamma size distribution. This distribution provides a more realistic representation of the small rain drops. To get accurate information on raindrop size distributions with the above method, the air motions must be removed from the observed Doppler velocities.

The purpose of this paper is a preliminary examination of raindrop size distributions using dual-parameter (reflectivity, Doppler velocity) airborne radar measurements from nadir-pointing X-band ER-2 Doppler radar (EDOP) located on the high-altitude ER-2 aircraft (Heymsfield et al. 1996). EDOP provides similar measurements to ground-based vertically pointing radars except that extensive regions can be covered in short times; ground-based vertical-incidence radars provide time-height measurements which and in all but a few precipitation systems time is a poor substitute for distance. The ER-2 participated in three recent Tropical Rain Measuring Mission (TRMM) field campaigns: Texas and Florida Underflights Experiment (TEFLUN-A and TEFLUN-B), and TRMM-Brazil (Amazonia). TEFLUN was conducted for the purpose of validation of the rain

measurements from the TRMM satellite. In addition, flights were made during the Convection and Moisture Experiment (CAMEX-3) which was aimed at hurricane studies. The current data sets from EDOP provide the opportunity to examine the general properties of the vertical structure of the raindrop size distributions in these different precipitation regimes.

EDOP samples Doppler velocity, v_D , and reflectivity factor, Z , with a gate spacing of 37.5 m (vertical resolution) and at 0.5 s intervals (100 m along-track sampling frequency). The antenna beamwidth is about 3° which provides a spot size of about 1.2 km at the surface. Calibration accuracy of EDOP is about 1-2 dB.

2. APPROACH

The radar reflectivity factor Z in mm^6m^{-3} can be given by (e.g. Ulbrich 1992):

(1)

where D (cm) is particle equivalent spherical diameter, $N(D)$ in $\text{m}^{-3}\text{cm}^{-1}$ is number of raindrops per unit volume per unit size interval, D_0 is the median particle diameter, the Gamma size distribution is assumed $N(D) = N_0 D^\mu e^{-\Lambda D}$, where μ is the shape parameter, and $\alpha = \Lambda D_0 = 3.67 + \mu + 10^{-0.3(9+\mu)}$. $N_0(\mu) = 6.4 \times 10^4 \exp(3.2\mu)$ has been shown observationally and theoretically by Ulbrich (1983). The integration limits D_{\min} and D_{\max} are assumed $0 \rightarrow \infty$, though several papers have dealt with truncated limits. The reflectivity-weighted Doppler velocity v_z (ms^{-1}) is given by:

$$v_z = \frac{\int_{D_{\min}}^{D_{\max}} v(D) N(D) D^6 dD}{\int_{D_{\min}}^{D_{\max}} N(D) D^6 dD} \quad (2)$$

where $v(D)$ is the drop fallspeed distribution. Furthermore, Ulbrich (1994) has derived the reflectivity-weighted Doppler velocity v_z as a function of μ by assuming the Gunn-Kinzer fallspeed relation at ground level (1013 mb), i.e., $v(D) = 9.65 - 10.3 e^{-6D}$. Assuming that vertical air motions are negligible, Eq. 2 by elimination of parameters can be given as a function of μ and Z :

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$$v_z(\mu) = 9.65$$

$$-10.3 \left\{ 1 + 6 \left[\frac{Z}{N_o(\mu) 10^6 \Gamma(7+\mu)} \right]^{1/(7+\mu)} \right\}^{-(7+\mu)} \quad (3)$$

This relation applies to ground level (1013 mb); v_z at other altitudes is obtained by multiplying it by $[\rho/\rho_0]^{0.44}$ where ρ and ρ_0 are the air density at the surface and measurement height, respectively. Eq. 3 has a major advantage over power law relations used extensively in the literature: v_z is asymptotic with increasing reflectivity rather than increasing monotonically with Z . The rain rate R can also be computed as a function of μ (Ulbrich 1992):

$$R(\mu) = F(\mu) Z v_z^{-3.48}, \quad (4)$$

where F is an analytic function of μ .

Figure 1 shows the dependence of v_z on μ using Eq. 3; a commonly used power law relation is also plotted. At 40 dBZ, the variation of μ from -2 to 6 results a fairly substantial 4 ms⁻¹ variation in v_z . Figure 2 shows the Gamma size distribution corresponding to $v_z = 6, 8$ ms⁻¹ and $\mu = -2$ to 4. The resulting range of generated curves are typical of reflectivities observed in EDOP data sets. Larger v_z for a given μ implies larger D_0 and a larger Z .

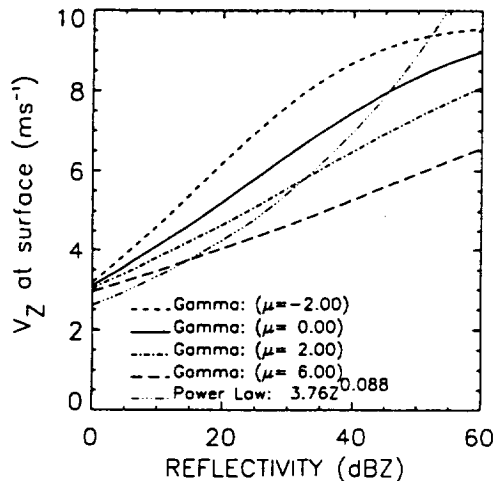


Figure 1. v_z - Z relation as a function of μ .

3. EXAMPLE.

The approach here is to fit Eq. 3 to the EDOP vertically pointing Doppler velocity v_D and Z observations to obtain μ in the Gamma distribution. The main assumption in applying Eq. 3 to EDOP observations is that stratiform regions are fairly extensive and that the mean vertical air motions over this region are negligible. Eq. 3 is modified with an additive constant because widespread vertical motions can be present. Thus, if one has large sample of v_D and Z measurements from the same region, then μ can be obtained by fitting the altitude-adjusted observed v_D with the following:

$$\left(\frac{\rho}{\rho_0} \right)^{0.44} v_D = C + v_z(\mu), \quad (4)$$

where v_z is obtained from Eq. 3 and C is a constant which consists of the mean mesoscale vertical motion plus biases caused by incorrect removal of aircraft motion. This fitting method provides a

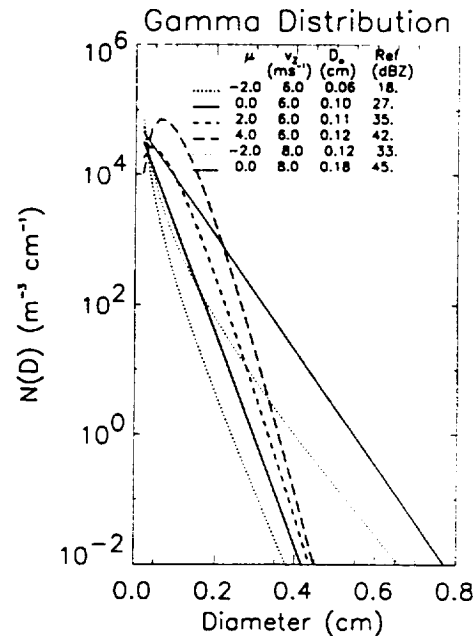


Figure 2. Gamma distribution for two values of v_z , assuming various values of the shape parameter μ .

global estimate of μ and C within some defined height interval, not a point-by-point estimate of the values. Besides the inhomogeneity of the size distribution over the analyzed region, a major source of error in this approach is the presence of small scale vertical air motions. In addition, small scale aircraft motions are not always fully removed resulting in an error in the v_D used in the calculation.

We provide an example of Eq. 4 applied to data (Fig. 3) from an ER-2 flight on 13 January 1995 covering a stratiform region trailing a squall line off

the Gulf coast of the U.S. The rain region between the surface and 400 m below the freezing level, is divided into 525 m intervals and then fitted using a non-linear curve fitting routine. The vertical axis corresponds to observed Doppler velocities adjusted to the surface, with a range of values from about 3 to 9 ms⁻¹. The reflectivities in the data set range from about 20 to 45 dBZ; no attenuation correction has been applied to this flight line. About 10,000 points went into the fit and while there is scatter of the points, the general shape of the cluster of points is fitted reasonably well by the curves. The fitted curves in Fig. 3 indicate that μ ranges from -0.84 at the top layer (1.5-2 km) to 1.2 at the bottom layer (0.4-0.9 km), implying a nearly exponential distribution. The calculated C ranges from about +0.6 ms⁻¹ at the top to +1.3 ms⁻¹ in the bottom layer which suggests either a mesoscale downdraft or aircraft motions. For the same v_z , a larger μ implies a shift toward larger droplets. This would be consistent with subsidence-induced evaporation as was present with this case. The downward increase in C is consistent with the subsiding rear inflow observed with the squall line; this is probably not caused by aircraft motions which would affect all levels uniformly.

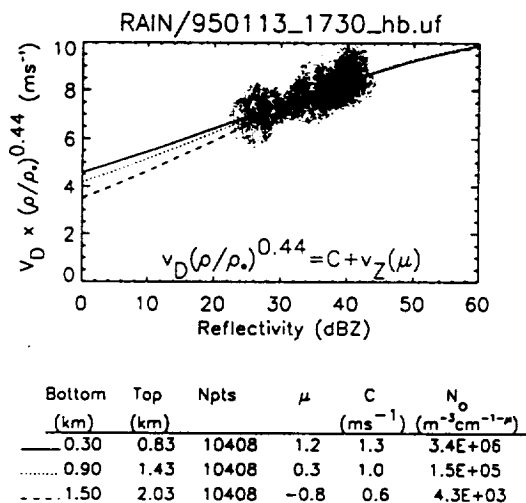


Figure 3. Observed measurements from squall line stratiform on 13 January 1995 fitted with Eq. 4.

5. CONCLUSIONS.

This paper has examined an approach for estimating parameters of Gamma rain size

distribution using only Doppler velocity and reflectivity measurements from an airborne nadir-pointing Doppler radar. The approach is best suited for widespread uniform stratiform regions without significant small-scale vertical motions present. Although this approach has some limitations when compared with other multiparameter approaches (e.g., dual-wavelength, dual-polarization, Doppler spectrum), it provides useful information for understanding general characteristics of the drop size distributions, rain rates, and liquid water content. Additional cases are being examined with the above approach. In particular, this method may prove useful in estimating drop size distributions and rain rates in feeder bands of hurricanes sampled by EDOP. In addition, subtracting the best estimate of $v_z(\mu)$ from v_D can provide an improved estimate of local air motions.

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